Chinese Patent Application No. CN 1264228A

Job No.: 228-119138
Ref.: CN patent No. 1264228/PU030051 US/RBL(Kathleen)/Order No. 8363
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NATIONAL INTELLECTUAL PROPERTY BUREAU OF THE PEOPLE'S REPUBLIC OF CHINA
LAID-OPEN PATENT APPLICATION NO. CN 1264228A

Int. Cl.[7]:	H 04 J 13/00
Filing No.:	00114058.2
Filing Date:	February 1, 2000
Publication Date:	August 23, 2000

AUTOMATIC FREQUENCY CONTROL METHOD AND DEVICE IN WIDEBAND CODE DIVISION MULTIPLE ACCESS SYSTEM

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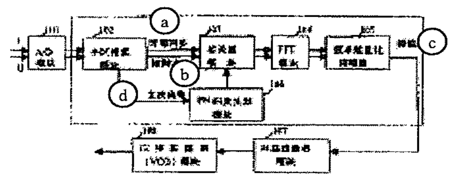
Number of pages of Claims:	1
Number of pages of Specification:	7
Number of pages of attached Figures:	2

[There are no amendments to this patent.]

Abstract

An automatic frequency control (AFC) method in a wideband code division multiple access (WCDMA) system applicable to the frequency division duplex (FDD) mode in the third generation of communication includes the following steps: a cell search is performed to obtain slot synchronization, frame synchronization, and a primary scrambling code number; the information obtained from the cell search is used to descramble and dispread the common pilot

channel (CPICH) to obtain a common pilot code; fast Fourier transformation is performed to transform the signal to the frequency domain, followed by energy analysis to extract frequency offset information. The present invention also provides an automatic frequency control device used for realizing said method.



Key:	a	Slot synchronization
	b	Frame synchronization
	c	Frequency offset
	d	Primary scrambling code number
	101	A/D module
	102	Cell search module
	103	Correlator module
	104	FFT module
	105	Frequency energy comparison module
	106	PN code generator module
	107	Loop filter module
	108	Voltage controlled oscillator (VCO) module

<u>Claims</u>

1. An automatic frequency control method in wideband code division multiple access system including the following steps:

1) a cell search is performed to obtain slot synchronization, frame synchronization, and a primary scrambling code number;

2) the information obtained in step 1) is used to descramble and dispread the common pilot channel to obtain a common pilot code;

3) fast Fourier transformation is performed to transform the signal to the frequency domain, followed by energy analysis to extract frequency offset information.

2. A device for realizing the automatic frequency control method described in Claim 1 including

a cell search module (102) used to obtain slot synchronization, frame synchronization, and a primary scrambling code number with respect to the signals obtained by processing a

primary synchronization channel, secondary synchronization channel, and primary common control channel in received signals,

characterized by also having the following:

a PN code generator module (106) that uses the primary scrambling code number generated by cell search module (102) to generate the corresponding PN code and descrambles and dispreads the CPICH channel under control of a slot synchronization signal and a frame synchronization signal;

correlator (103) that outputs the symbols of CPICH, with each symbol including frequency offset information;

FFT module (104) that performs fast Fourier transformation to the discrete CPICH symbols output from correlator (103) to obtain the frequency domain signals of the CPICH;

frequency energy comparison module (105) that compares each section of the obtained frequency domain signals to obtain the peak frequency in each section and analyzes the relative position of the peak frequency to obtain frequency offset information.

Specification

Automatic frequency control method and device in wideband code division multiple access system

The present invention pertains to a wideband code division multiple access system (WCDMA). More specifically, the present invention pertains to an automatic frequency control (AFC) method and a device for a wideband code division multiple access system under the frequency division duplex (FDD) mode.

The receiver in a wireless communication system usually includes an AFC module. This is because the oscillation frequency for signal modulation in the transmitter is different from the oscillation frequency for signal mixing in the receiver (we call this the fixed frequency offset). After mixing, the frequency component of the fixed frequency offset is left in the baseband signal. In the meantime, a Doppler frequency offset caused by movement will also remain in the baseband signal through mixing and filtering. We call both said frequencies frequency offset. The influence of frequency offset on baseband signal processing proceeds from a quantitative change to a qualitative change. If the frequency offset is very small, its influence on signal processing is also very small. The larger the frequency offset, the more significant the influence. If the frequency offset exceeds a certain value, the signals will undergo phase superimposition, which makes it impossible to correctly judge the content of the data. Therefore, a communication system usually has an AFC device to correct frequency offset so that the receiver and transmitter can be synchronized at a certain accuracy under different circumstances.

US Patent No. 5,828,710 "AFC FREQUENCY SYNCHRONIZATION NETWORK" provides an AFC correction method applicable to a Eureka-147 digital audio broadcast system (DAB). It first digitalizes signals. Then, the signals are transported into the frequency domain by means of fast Fourier transformation (FFT). The direction of frequency offset is determined (positive or negative) based on the statistical variation tendency of the frequency energy. A voltage controlled oscillator (VCO) is adjusted stepwise based on said direction. The step of each adjustment is 1/2 of the previous adjustment. After each adjustment, it is necessary to estimate the frequency offset direction based on the statistical variation of the frequency energy. This process is repeated until the step is smaller than a certain set value. At that time, it is deemed that the frequency offset has been virtually compensated. Obviously, this method requires that the difference in the frequency energy before and after each adjustment exceed the combined influence of Doppler attenuation and noise on the frequency energy. Otherwise, it is impossible to determine the frequency offset direction based on the variation in the frequency energy.

This method, however, is inapplicable to a WCDMA system because said digital audio broadcast DAB system is a frequency modulation system with a carrier on the order of 100 MHz, while the carrier of WCDMA is 2 GHz. Therefore, in the same ground environment and at the same movement speed of the receiving terminal, the signal of a WCDMA system will attenuate much more significantly and faster than the signal of a DAB system. Therefore, in a WCDMA system, the statistical frequency energy variation direction cannot indicate the direction of the frequency offset.

The objective of the present invention is to provide an AFC method and device applicable to the mobile terminal of a WCDMA system in order to implement effective automatic frequency control to guarantee that the transmitter and the receiver are synchronized at a certain accuracy.

The present invention provides an automatic frequency control method in a wideband code division multiple access system including the following steps:

1) a cell search is performed to obtain slot synchronization, frame synchronization, and a primary scrambling code number;

2) the information obtained in step 1) is used to descramble and dispread the common pilot channel (CPICH) to obtain a common pilot code;

3) fast Fourier transformation is performed to transform the signal to the frequency domain, followed by energy analysis to extract frequency offset information.

The automatic frequency control device used for realizing said automatic frequency control method includes:

a cell search module used to obtain slot synchronization, frame synchronization, and a primary scrambling code number with respect to the signals obtained by processing a primary

synchronization channel, secondary synchronization channel, and primary common control channel in the received signals,

and is characterized by also having the following:

a PN code generator module that uses the primary scrambling code number generated by the cell search module to generate a corresponding PN code and descrambles and dispreads the CPICH channel under control of a slot synchronization signal and a frame synchronization signal;

a correlator that outputs the symbols of CPICH, with each symbol including frequency offset information;

an FFT module that performs fast Fourier transformation to discrete CPICH symbols output from a correlator to obtain the frequency domain signals of the CPICH;

and a frequency energy comparison module that compares each section of the obtained frequency domain signals to obtain the peak frequency in each section and analyzes the relative position of the peak frequency to obtain frequency offset information.

Compared with other frequency offset estimation methods, the frequency offset estimation method disclosed in the present invention has the following advantages:

1) It is easy to realize. This method has no extra requirement on the system as far as hardware is concerned. That is, it can be realized using the original hardware resources of the system.

2) The accuracy is adjustable. If the three pieces of information provided by the cell search are accurate, the estimation accuracy of this method is dependent on the transformation length of the FFT. The longer the transformation length, the higher the accuracy. However, the operating time is extended as the transformation length increases. Therefore, the adjustable range of the accuracy is within the allowed operating time.

3) This method is particularly suitable for a WCDMA system. In a WCDMA system, prior to the cell search, the signals in all the channels are spread spectrum signals as random combinations of "+1" and "-1." Even after pulse shaping and going through a mobile channel, the spectrum of the signals is still similar to a noise spectrum. The frequency of the frequency offset signal is almost submerged by the signal spectrum and is very difficult to extract. Since other frequency offset estimation methods estimate directly the received signals, the general frequency offset estimation method cannot be used in this case. After the CPHCH is descrambled and dispreaded after the cell search, the signal content of the CPICH is completely resumed to "1." At that time, the signal spectrum is basically 0. In this way, it is possible to separate the signal spectrum from the frequency of the frequency offset, and it is very easy to extract the frequency offset information by applying FFT. Therefore, it can be said that the frequency offset estimation method provided by the present invention is specially designed for a WCDMA system.

In the following, the present invention will be explained in more detail with reference to the attached figures.

Figure 1 is a block diagram illustrating the receiver in a normal wireless communication system.

Figure 2 is a typical application block diagram of the AFC device applicable to a WCDMA system disclosed in the present invention.

Figure 3 is a diagram illustrating the signals in the CPICH descrambling and dispreading step, a key step in the automatic frequency control method disclosed in the present invention.

In the following, the present invention will be explained in more detail.

After frequency conversion to baseband and sampling, the received signal can be expressed as follows.

$$\rho(k) = \alpha e^{j(\frac{\Delta\omega}{N\omega_0}k+\varphi)}[I(k)+jQ(k)]+n(k) \qquad (1)$$

wherein, k = 0, 1, 2 …, I(k), Q(k) are received original data, n(t) is white Gaussian noise, α is channel attenuation, φ is a random phase uniformly distributed in the mobile channel, $N\omega_0$ is the sampling frequency of the chip, ω_0 is the speed of the chip which is 3.84 MHz, N is the number of sampling points of a chip. In the following discussion, N = 1. $\Delta\omega$ is frequency offset, including the fixed frequency offset $\Delta\omega_0$ between the two oscillations on the transmission and receiving sides and the Doppler frequency offset $\Delta\omega_d$ caused by movement.

Assuming that the cell search effectively identifies slot synchronization, frame synchronization, and the scrambling code in the case of having an initial frequency offset, we can use the common pilot channel to conduct an estimation. Prior to estimation, the common pilot channel is descrambled and dispreaded to obtain the data symbol (SYMBOL) of the common pilot channel. After the obtained data are simply filtered, fast Fourier transformation (FFT) is performed to obtain the spectrum of the common pilot channel symbol. After comparison, the frequency with the highest energy is used as the obtained frequency offset $\Delta\omega$ as shown in Figure 2.

Equation (1) can be separated into a real part and a virtual part by setting

$$\theta(k) = \frac{\Delta\omega}{\omega_0}k + \varphi,$$

$$\begin{aligned} I_c(k) &= \alpha[I(k)\cos\theta(k) - Q(k)\sin\theta(k)] + n_1(k) \\ Q_c(k) &= \alpha[I(k)\sin\theta(k) + Q(k)\cos\theta(k)] + n_2(k) \end{aligned} \qquad (2)$$

The Ic(k) and Qc(k) of the CPICH are descrambled and dispreaded. In the case of complete synchronization, all of the symbols of the CPICH are converted to "1," while the data in other channels are still pseudo random data similar to white noise, since their channel codes or

scrambling codes are different. Said random data are combined with the original noise to form new white noise $n_1(k)$ and $n_2(k)$. Therefore, after correlative accumulation, the following is obtained (the accumulation length is SF, the SF of the CPICH = 256):

$$
\begin{aligned}
I_s(m) &= \alpha \sum_{k=256m}^{256(m+1)-1} [\cos\theta(k) - \sin\theta(k)] + \sum_{k=256m}^{256(m+1)-1} n_1'(k) \\
Q_s(m) &= \alpha \sum_{k=256m}^{256(m+1)-1} [\cos\theta(k) + \sin\theta(k)] + \sum_{k=256m}^{256(m+1)-1} n_2'(k)
\end{aligned}
\tag{3}
$$

wherein, m=0, 1, 2 ... Since the mean value of white noise is "0" in a sufficiently long integration interval, both $\sum_{k=256m}^{256(m+1)-1} n_1(k)$ and $\sum_{k=256m}^{256(m+1)-1} n_2(k)$ are approximated to be "0." Then, one has the following:

$$
\begin{aligned}
I_s(m) &= 2\alpha \sum_{k=256m}^{256(m+1)-1} \cos[\frac{\Delta\omega}{\omega_0}k + \varphi + \frac{\pi}{4}] \\
Q_s(m) &= 2\alpha \sum_{k=256m}^{256(m+1)-1} \sin[\frac{\Delta\omega}{\omega_0}k + \varphi + \frac{\pi}{4}]
\end{aligned}
\tag{4}
$$

wherein,

$$
\sum_{k=256m}^{256(m+1)-1} \cos(\frac{\Delta\omega}{\omega_0}k + \varphi + \frac{\pi}{4}) = \mathrm{Re}\{\frac{1-e^{j256\frac{\Delta\omega}{\omega_0}}}{1-e^{j\frac{\Delta\omega}{\omega_0}}} e^{j(256m\frac{\Delta\omega}{\omega_0}+\varphi+\frac{\pi}{4})}\}, \tag{5-a}
$$

$$
\sum_{k=256m}^{256(m+1)-1} \sin(\frac{\Delta\omega}{\omega_0}k + \varphi + \frac{\pi}{4}) = \mathrm{Im}\{\frac{1-e^{j256\frac{\Delta\omega}{\omega_0}}}{1-e^{j\frac{\Delta\omega}{\omega_0}}} e^{j(256m\frac{\Delta\omega}{\omega_0}+\varphi+\frac{\pi}{4})}\}, \tag{5-b}
$$

When frequency offset $\Delta\omega$ has a certain value, Is(m) and Qs(m) are functions of $e^{j256m\frac{\Delta\omega}{\omega_0}}$. Here, 256m is the 256mth point out of the sampling points (speed 3.84 MHz) of the chip. It is equivalent to the mth point among the sampling points (speed 15 kHz) of the symbol. Therefore, the symbol functions Is(m) and Qs(m) are actually functions of $e^{jm\frac{\Delta\omega}{\omega'_0}}$, wherein, ω'_0 is the speed of the symbol, which satisfies ω_0/ω'_0 = SF= 256. In this way, the frequency offset information $\Delta\omega$ can be obtained by processing the spectra of Is(m) and Qs(m). Since FFT is carried out at the speed of the symbol, the obtained frequency offset with the highest energy is related to the symbol speed. For example, if FFT is performed on 256 points, and the highest frequency is at the 38th point, the actual frequency of that point is as follows.

(38/256) * 15 kHz = 2.23 kHz

Now, the problem is whether a cell search can effectively identify slot synchronization, frame synchronization, and a scrambling code under the influence of an initial frequency offset.

Since the primary synchronization channel codes in the synchronization channel are correlated during the slot synchronization process, the correlation output is the same as the

aforementioned correlation result of the CPICH. Therefore, the average sum of I, Q after correlation is as follows:

$$I_s^2(t)+Q_s^2(t)=\alpha^2\left(\frac{1-e^{j256\frac{\Delta\omega}{\omega_0}}}{1-e^{j\frac{\Delta\omega}{\omega_0}}}\right)^2=\alpha^2\frac{1-\cos 256\frac{\Delta\omega}{\omega_0}}{1-\cos\frac{\Delta\omega}{\omega_0}} \qquad (6)$$

Since frequency offset $\Delta\omega$ is very small compared with chip speed ω_0, $\Delta\omega/\omega_0$ is almost 0. Equation (6) can be approximated as follows.

$$I_s^2(t)+Q_s^2(t)=(256\alpha)^2 \qquad (7)$$

Since this is independent of frequency offset, slot synchronization is not affected by frequency offset when the frequency offset is relatively small.

Frame synchronization and a scrambling code group number are identified by looking them up in a table using the secondary synchronization channel code number. The code number is derived based on the peak position of the average sum of the FHT correlation output. It is barely affected by frequency offset for the same reason.

Similarly, when the frequency offset is relatively small, the process of generating the primary scrambling code is barely affected by the frequency offset. Therefore, generation of the primary scrambling code at that time can be deemed independent of frequency offset. A simulation shows that if the initial frequency offset is $\Delta f < 3000$ Hz, a cell search can still complete identification of slot synchronization, frame synchronization, and the primary scrambling code. This means that the aforementioned frequency offset correcting method is feasible.

Figure 1 shows the receiver in a normal wireless communication system. After a signal is received from the antenna, frequency band gating is performed to the signal through bandpass filter 1. Then, the signal is input into high frequency power amplifier 2, followed by entering down frequency converter 3 (such as a GSM that performs down frequency conversion from 900 MHz or 1800 MHz to an intermediate frequency bandwidth, which is not specified and is usually tens of MHz). The signal is converted into a baseband signal through intermediate frequency demodulator 4, followed by passing through lowpass filter 5 and A/D converter 6 to become a digital signal. The digital signal passes through digital baseband signal processor 7 and AFC 8 so that the frequency offset correction signal is extracted and sent to phase lock loop PLL 9 to correct frequency error.

The automatic frequency control method provided by the present invention is described as follows.

1. Cell search

A cell search is carried out in three steps.

1) A specific correlator is used to correct the codes in the primary synchronization channel (P-SCH) to obtain slot synchronization.

2) On the basis of slot synchronization, a series of treatments is carried out to the codes in the secondary synchronization channel (S-SCH) to obtain the secondary synchronization channel code number of each slot. Then, said code numbers are processed to realize frame synchronization and obtain the code group number of the primary scrambling code.

3) After slot synchronization and frame synchronization are completed, the known code group number is used for correlation with the primary common control channel (P-CCPCH). After comparison, the offset of the primary scrambling code in that group is obtained so that the primary scrambling code number of that cell is obtained.

After said three steps are completed, slot synchronization, frame synchronization, and a primary scrambling code number are obtained. These three pieces of information are the basis of normal operation of the entire system.

The details of the cell search method are disclosed in the Chinese Patent Application 99117207.8 <<Slot synchronization device during WCDMA cell search>> and 99117209.4 <<Scrambling code number identification method and frame synchronization device in WCDMA cell search>> proposed by the present applicant on November 12, 1999.

2. Descramble and dispread

On the basis of slot synchronization and frame synchronization, the known primary scrambling code number is used to descramble and dispread the common pilot channel (CPICH) (it is known that the spread spectrum channel codes of the CPICH are all "1") to obtain common pilot symbols. All of the common pilot symbols were formerly "1." However, after going through the mobile channel, the pilot symbols are modulated by the frequency offset. Therefore, the obtained common pilot symbols include the frequency offset information. The CPICH channel is selected to estimate the frequency offset because all of the contents of the CPICH channel, which are "1," are known, and the channel code (determined) and scrambling code (that is, the primary scrambling code of this cell obtained from the cell search) are also known. In this way, a pseudo random code of the CPICH (PN code, including channel code and scrambling code, used for the final scrambling and spreading or descrambling or dispreading) is determined. Therefore, after the cell search is completed, the PN code is used directly to descramble and dispread the CPICH without any other information being necessary. Also, since its emission power is relatively high, it is good for identification.

The dispreading process can be described based on Figure 3. Signal 110 is the data signal a(t) prior to spreading. It is the aforementioned symbol. The symbol width is Ts. Signal 111 is spreading code b(t), which is also known as the channel code. Its width is Tc, which satisfies Tc=Ts/SF. SF is a spreading factor. Signal 112 is data signal c(t) after spreading. It is obtained by multiplying signal 111 and signal 110. Since both the data symbol and spread spectrum code d(t) only include two levels: +1 (high level) and –1 (low level), the multiplication result is as shown in Figure 3. The frequency bandwidth of the signal after spreading is SF times that prior to spreading. Therefore, said frequency spreading process is known as "spreading." The spreading process is described above. The dispreading process is the opposite to the spreading process. They are complementary with respect to each other. Signal 113 is a spread spectrum code d(t) used for dispreading. It is actually the spread spectrum code used during spreading, that is, d(t) = b(t). During dispreading, signal 113 is multiplied by signal 112 to resume signal 110, which is the resumed data signal 114. If the process is carried out correctly, one should have e(t) = a(t). This can be expressed as follows.

$$e(t) = c(t) * d(t) = [a(t) * b(t)] * d(t) = a(t) * [b(t) * d(t)] = a(t) * b^2(t) = a(t) \qquad (1)$$

Note: During the spreading or dispreading process, the two signals multiplied together must be synchronized in time order. Only when they are synchronized with each other will one have b(t) = d(t), and b(t)*d(t) = b^2(t) = 1 in equation (1) will become valid. The original data signal can be correctly resumed in this way.

The descrambling process is exactly the same as the dispreading process.

3. Extract the frequency offset information

The signals are converted to the frequency domain through FFT. The frequency offset information can be extracted through comparison. It must be pointed out that any wireless channel has a multipath effect. The fixed frequency offset is the same for each path, while the Doppler frequency offset varies, since the angle between each path and the mobile terminal is different. The cell search only completes synchronization of the most powerful path among the plural paths. Therefore, the frequency offset obtained using this method is the frequency offset of the most powerful path. Its Doppler frequency offset only represents the most powerful path. However, the maximum ratio combination is usually performed when combining the signals of plural paths. That is, the more energy a path has, the larger the weighted value during combination. Therefore, it is very effective to use the frequency offset of the most powerful path estimated using this method for AFC correction.

Figure 2 shows the AFC device disclosed in the present invention in a WCDMA system.

The AFC device disclosed in the present invention has five main parts, that is, a cell search module, correlator, PN code generator, FFT operation module, and energy comparison module. In this case, the correlator and the PN code generator are exactly the same as the correlator and PN code generator used in many places of the wideband code division multi-access system. They can be realized by a field-programmable logic array (FPGA) or a digital signal processor (DSP). The FFT operation and comparator can also be realized using a DSP.

The part within the dotted line block shown in Figure 2 is the automatic frequency control device disclosed in the present invention. Analog/digital conversion module 101 converts the received analog signals into digital signals and sends the digital signals to cell search module 102. Module 102 processes the primary synchronization channel, secondary synchronization channel, and primary common control channel in the received signals to obtain slot synchronization, frame synchronization, and a primary scrambling code number of the signals. PN code generator module 106 uses the primary scrambling code number generated by module 102 to generate the corresponding PN code. The CPICH channel is descrambled and dispreaded under control of the slot synchronization signal and frame synchronization signal. Correlator 103 outputs the symbols of the CPICH. Each symbol includes frequency offset information. The discrete CPICH symbols are input into FFT module 104 to carry out FFT to obtain the frequency domain signals of the CPICH. Frequency energy comparison module 105 sections and compares the obtained frequency domain signals to obtain the peak frequency in each section. The frequency offset information can be obtained by analyzing the relative position of the peak frequency. The obtained frequency offset information is input into loop filter module 107, which is actually a lowpass filter that can smooth the frequency offset signal. The smoothed frequency offset signal is sent to voltage controlled oscillator module (VOC) [sic; (VCO)] 108, which adjusts the output signal frequency of the oscillator based on the voltage level of the input signal. Its output signal has undergone intermediate frequency mixing. In this way, the frequency offset can be corrected to realize automatic frequency correction.

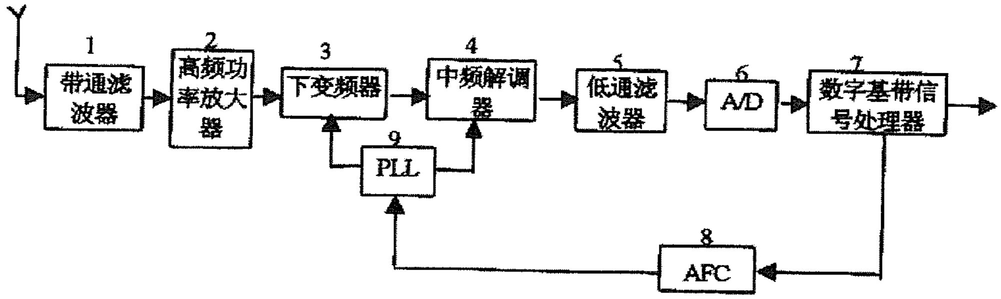


Figure 1

Key:
1 Bandpass filter
2 High-frequency power amplifier
3 Down frequency converter
4 Intermediate frequency demodulator
5 Lowpass filter
7 Digital baseband signal processor

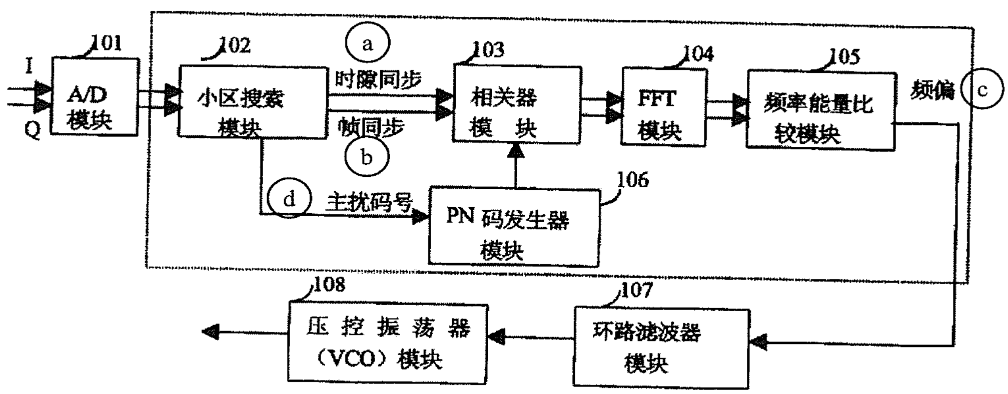


Figure 2

Key:
a Slot synchronization
b Frame synchronization
c Frequency offset
d Primary scrambling code number
101 A/D module
102 Cell search module
103 Correlator module
104 FFT module
105 Frequency energy comparison module
106 PN code generator module
107 Loop filter module
108 Voltage controlled oscillator (VCO) module

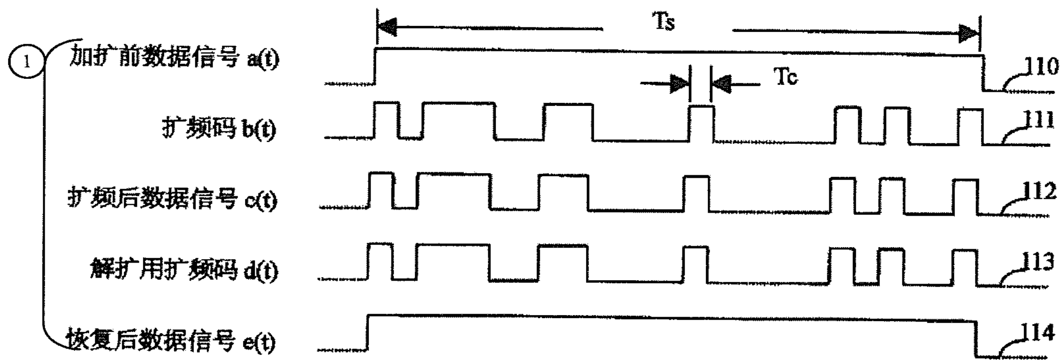


Figure 3

Key: 1 Digital signal a(t) prior to spreading
Spread spectrum code b(t)
Data signal c(t) after spreading
Spread spectrum code d(t) for dispreading
Resumed data signal e(t)